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AIRBORNE HEIGHT-FINDING BASED ON THE INTERFERENCE PRINCIPLE - METHOD 1

[UNCLASSIFIED TITLE]

AIRBORNE HEIGHT-FINDING BY THE LOBE-COUNTING METHOD

[CONFIDENTIAL TITLE]

A. L. Franta

Search Radar Branch
Radar Division

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September 4, 1958

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CONTENTS

ABSTRACT
(Confidential)

Work has been carried out to evaluate the accuracy of the lobe-counting method of height-finding in the presence of various sea states. Experiments were performed with a low-power uhf (425 Mc) radar in a ZPG-2 airship flying at 2800 feet. The altitudes of aircraft targets flying at constant altitudes between 3200 and 35,000 feet were determined with accuracies ranging from about 9 percent at the lower altitudes to 4 or 5 percent at the medium and higher altitudes. Successful results were obtained with sea states as high as six. The operational feasibility of this method of height-finding was demonstrated by the barrier exercises performed.

PROBLEM STATUS

Problem R02-10 was closed April 4, 1958. This is a final report on this problem and on one phase of Problem R02-05 which continues.

AUTHORIZATION

NRL Problems R02-10 and R02-05
Projects NL 430-014 and NR 412-000,
Tasks 413-008 and 412-001

Manuscript submitted August 4, 1958

AIRBORNE HEIGHT-FINDING BY THE LOBE-COUNTING METHOD
[Confidential Title]

INTRODUCTION

Several CNO operational requirements* specify the development of long-range high-performance surveillance and height-finding equipment for airborne early warning and control. The general functions required to be performed are:

1. long-range early warning, identification, and tracking of air targets over sea or land to meet the threat of minimum- and high-altitude supersonic aircraft attacking a fleet,

2. direct control of our fighter aircraft in interception of unidentified aircraft approaching a force, and

3. determinations of air target height above the surface at long range.

The minimum acceptable limits of operational performance require the carrier-based aircraft system to have an initial detection range (with 90 percent probability of detection and without the use of IFF) of 150 nautical miles on a five-square-meter target and a land-based aircraft system, 200 nautical miles on a one-square-meter target. The systems should be capable of determining the altitude of any target between the surface and 80,000 feet with an accuracy of ±5000 feet at 90 percent of their initial detection ranges.

The Navy air arm is presently equipped with the AN/APS-20E S-band search radar and the AN/APS-45 (or AN/APS-62) X-band height finder. The AN/APS-20E, the primary detection equipment on all AEW aircraft, is capable of 90 percent probability of detection on a one-square-meter target at 80 nautical miles (1). Its performance is seriously limited by sea return, and no satisfactory AMTI has been developed to date. The AN/APS-45 and AN/APS-62 radars are airborne height-finding systems with nodding type narrow-beam antennas, the AN/APS-45 being mounted on WV-2 aircraft, and the AN/APS-62 on ZPG-2W airships. After being coached onto a target by the search radar, the AN/APS-45 radar requires approximately a minute to accomplish an altitude determination at ranges always short of 100 nautical miles. Thus, the need for developing a combination search and height-finding radar system is real and urgent.

Several combination search and height-finding systems have been proposed and developed since the end of World War II. Of these, the stacked-beam systems, such as the AN/SPS-2, AN/FPS-7, and AN/SPS-13 radars, have pronounced advantages over other types like the V-beam or pencil-beam scanners. Several studies (2) have been made with regard to airborne stacked-beam systems, and an operational requirement specifying this development has been issued. †

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*No. AD-01501 (Revised) dated 22 March 1956
No. AD-01501-1 dated 25 April 1956
No. AD-06501 (Revised) dated 2 November 1955 (Carrier-Based AEW System)
No. AD-06502 (Revised dated 25 April 1956 (Land-Based AEW System)
No. AD-06502-1 dated 26 April 1956 (Lighter-than-air Aircraft)

†No. AD-01501-2 dated 18 April 1956

The only known active program is the airborne stacked-beam antenna development being carried out by the General Electric Company, Utica, New York, under Contract AF 33(600)34799. The basic difficulty with airborne stacked-beam systems is that the narrow vertical beamwidths required to achieve sufficient height accuracy demand the use of C-band or a higher frequency because of antenna size limitations. At these frequencies, there appears to be no prospect of attaining effective AMTI, and long-range detection is handicapped by adverse weather conditions and transmitter power limitations.

Low-frequency systems offer another approach to the problem of attaining a combination search and height-finding system. The detection capabilities of vhf and uhf radars, both shipborne and airborne, have been demonstrated (3, 4). At these frequencies, successful AMTI systems have been designed. Furthermore, these airborne systems should be capable of height-finding by the lobe-counting (5, 6, 7) frequency-modulation (8, 9), and time-difference method (9, 10, 11), all of which are based on the direct and sea-reflected propagation paths, the first two making use of the interference principle.

This study is concerned with lobe counting which required no modification to an existing radar and involved a minimum of instrumentation. The objectives of this project are: (a) to study the effect of angle of incidence and sea state on the interference pattern, and (b) to determine the accuracy with which the altitude of an isolated aircraft target can be measured.

THEORY

The theory for the calculation of field strength in the interference region for an elevated antenna is well known and has been covered in the literature (12, 13). The angular location of the lobes in the interference pattern is determined by the pathlength difference between the direct and reflected rays. This path difference is

$$\Delta R = \frac{2h_r h_t}{r} J(S,T) \tag{1}$$

where

h_r is radar height,

h_t is target height,

r is target range,

$J(S,T)$ is a correction factor from flat to spherical earth,

S is a function of h_r, h_t, and r, and

T is a function of h_r and h_t.

When a target flying at constant altitude changes range sufficiently to alter the path difference by one wavelength, it passes from one lobe to the next. Therefore, the number of lobes L traversed per nautical mile is

$$L = \frac{1}{\lambda}\left|\frac{d(\Delta R)}{dr}\right| = \frac{2h_r h_t}{\lambda}\left|\left[-\frac{J}{r^2} + \frac{1}{r}\cdot\frac{dJ}{dr}\right]\right|. \tag{2}$$

For given values of h_r, h_t, and r, the dimensionless distance and height parameters S and T are calculated from the equations

$$S = \frac{r}{\sqrt{2a_e h_r} + \sqrt{2a_e h_t}} \leq 1 \qquad (3)$$

$$T = \sqrt{\frac{h_r}{h_t}} \leq 1 \qquad (4)$$

where

$$a_e = 4/3 \text{ earth radius} = 4587 \text{ nautical miles.}$$

The function $J(S,T)$ is available in graphical form (12). From this graph and Eq. (3) and (4), a plot of J was made as a function of r, from which dJ/dr was determined graphically. Equation (2) was then evaluated for radar altitudes of 1000, 2000, and 3000 feet and a frequency of 425 Mc (Fig. 1).*

The use of these curves in determining altitude is complicated and difficult because of the nonlinear character of the relationship and the necessity for interpolating between curves. A more useful family of curves, shown in Fig. 2, relating lobes per mile to target altitude for several specified ranges, was plotted from the 3000-foot curves of Fig. 1. These curves were used in reducing the flight test data obtained in the height-finding trials.

INSTRUMENTATION

Height-finding by the lobe-counting method requires isolation of a target from all others in both range and azimuth. The instrumentation discussed here includes a range-gated tracker which, together with the horizontal directivity, isolates the target echo, and the equipment which records the variations of echo amplitude with range.

A block diagram of the primary units of the system is shown in Fig. 3. An interval of range continuously variable from 10 to 50 miles is selected from the 250-nautical-mile radar presentation and is displayed on a 3-inch A-scope. At the center of this interval, a segment of range, controllable from two to five times the radar pulse width, is selected. This bit of range is shown as a negative marker on the scope, and a gate of the same width is used to gate an i-f amplifier. The rejection ratio in the gated i-f amplifier is 40 to 50 db. The gated signal is amplified, demodulated using a peak detector, integrated, and applied to a standard single-channel Sanborn recorder (Model 127). Range information to the nearest 0.1 nautical mile is available from the position of the i-f gate, and is displayed on a Veeder-Root counter. The range-gated tracker and Sanborn recorder are shown in Figs. 4 and 5, respectively.

THE RADAR

The system chosen for use in the lobe-counting experiments was the low-power uhf radar produced under a joint effort by Group 45 of the Lincoln Laboratory, MIT, and the Naval Research Laboratory in 1953 and installed aboard a ZPG-2 airship attached to the

*This method of calculation was suggested by William S. Alderson, formerly of the Radar Division, NRL.

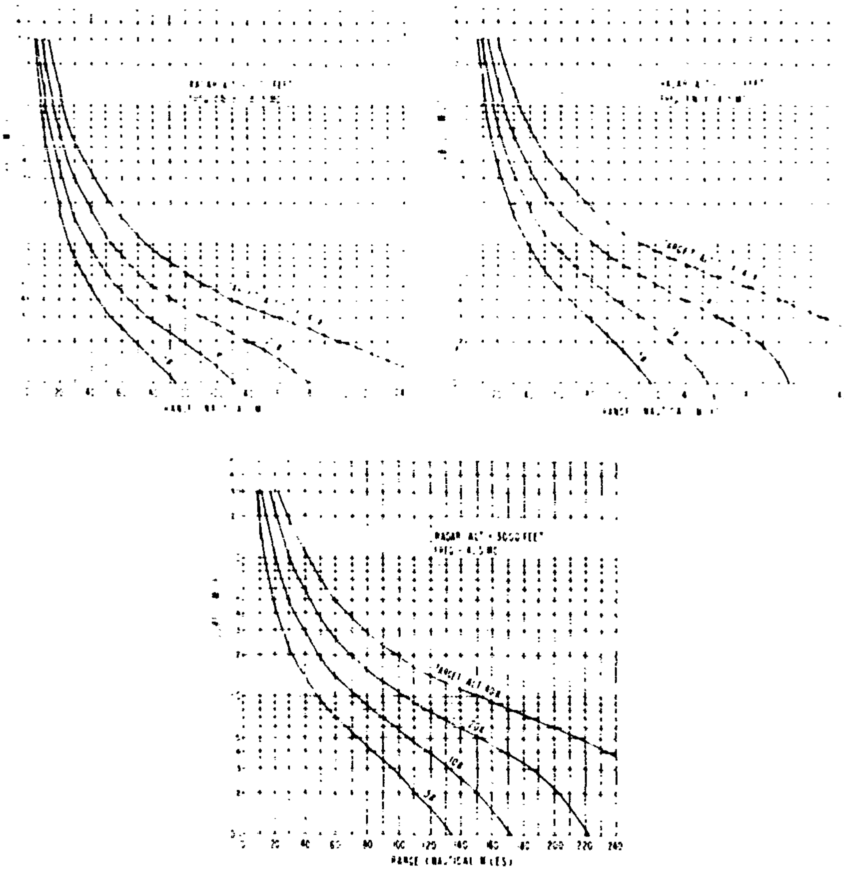

Fig. 1 - Theoretical curves of lobes per mile versus range for target altitudes of 5000, 10,000, 20,000, and 40,000 feet

Naval Air Development Unit, Naval Air Station, South Weymouth, Massachusetts (5): The radar transmitter of the original system was modified by incorporating a specially constructed tuning mechanism for the 7C22 oscillator (Fig. 6) and a set of tuning stubs for matching the antenna to the transmitter (Fig. 7). This resulted in the peak power output being increased from 140 to 280 kw. The stable local oscillator, which had been added to the original system for the purpose of conducting MTI studies, was replaced by a tunable local oscillator to facilitate using the receiver throughout the frequency range of the transmitter. The tunable receiver had a noise figure of 3.5 db

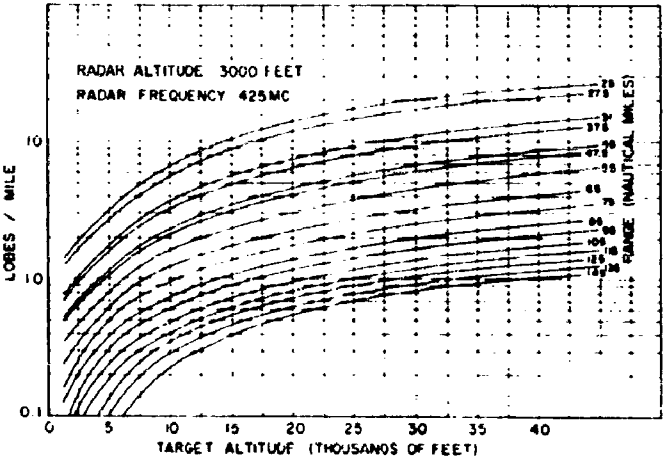

Fig. 2 - Theoretical curves of lobes per mile versus target altitude for several discrete ranges

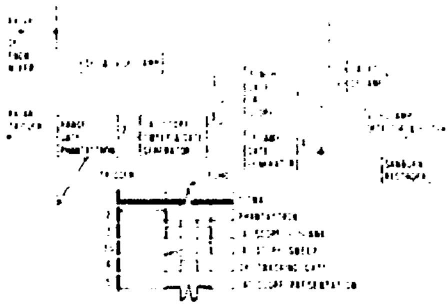

Fig. 3 - Block diagram of range-gated manual tracker and recorder

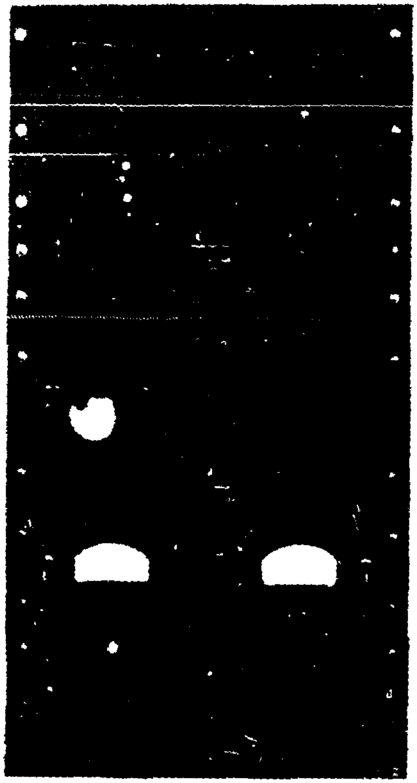

Fig. 4 - Range-gated tracker

Though the system performance was generally good, certain serious troubles were encountered during the height-finding trials. Erratic transmitter operation was traced to a defective antenna rotary joint, which was replaced with one of improved design. The special 6-μsec pulse-forming line installed in the original system shorted during flight tests in October 1955, and since no spares were available, it was replaced by a 8-μsec line obtained from other radar spares. During the latter part of the trials, full transmitter power was not attainable because of unstable operation at high output levels. Upon completion of the flight tests, the radar was disassembled and inspected. During the examination of the antenna, it was found that the center conductor of the main feed harness had fractured at a joint immediately following the input Tee section. The point of fracture showed evidence of arcing. This loss of continuity meant that for certain periods the radar was operated at a reduced power level with only half of the antenna feed system active, which resulted in a loss in range performance.

OPERATIONAL PROCEDURE

The operational procedure followed during the lobe-counting height-finding trials was the same for all tests performed. The radar and target aircraft met at a rendezvous point, either over Cape Ann, Massachusetts, or Nantucket Island, depending on the operational area assigned. On receipt of a command signal from the radar vehicle, the target plane proceeded on a course of 090 degrees at an assigned altitude. The airship flew the same course at a different altitude. After the initial detection had been made with the radar scanning, the antenna was stopped and placed in a "searchlight" mode. The target was tracked manually by maintaining the radar echo in the "notch" on the A-scope. As described previously, the signal variations were recorded on Sanborn tape. Range marks were added to the record manually at intervals of 10 miles or less with a time mark button. Each 10-mile interval was examined later to determine the number of lobe crossings per mile. When the target echo signal strength became too weak to record, both aircraft would execute a 180-degree turn and fly a course of 270 degrees for the point of origin (either Cape Ann or Nantucket). On the inbound runs the signal variations were recorded until the target was lost in clutter at a range of about 20 or 30 miles. At this point both aircraft again turned 180 degrees and began a new run.

Fig. 5 - Sanborn recorder

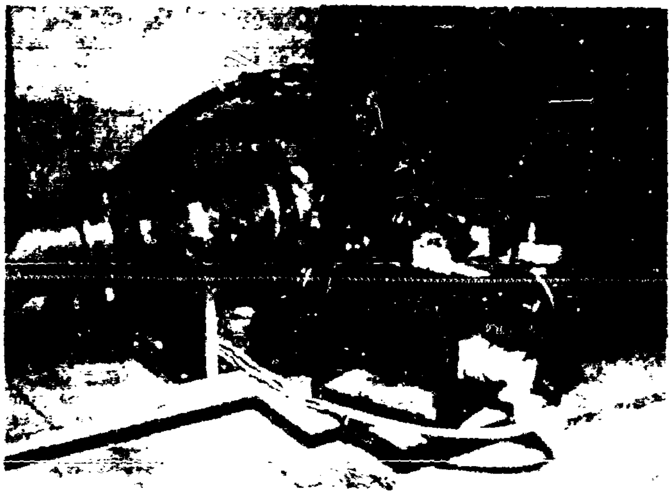

Fig. 6 - Specially constructed tuning mechanism

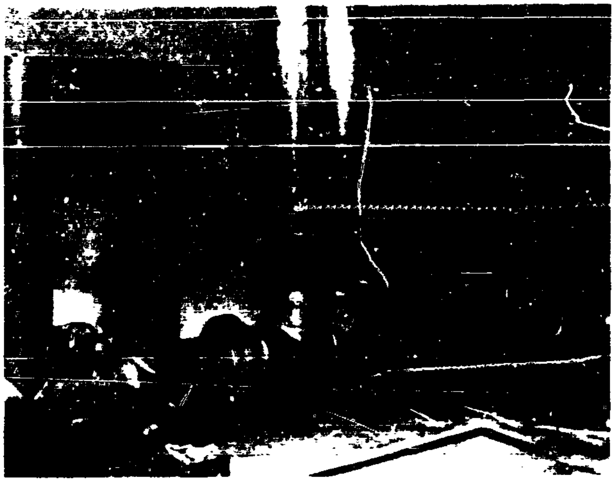

Fig. 7 - Tuning stubs (center) shown with relation to the duplexer (left) and transmitter (right

HEIGHT-FINDING TRIALS

Initial Experiments

The program began with a number of B-29 flights made during the week of May 9, 1955, off Cape Ann, Massachusetts. The weather was clear and the sea very calm. These initial trials were made with the radar at 1000, 2000, and 3000 feet and the target at 5000, 10,000 and 20,000 feet for each radar altitude. They demonstrated that a strong interference lobe pattern did exist and that the lobe-counting method could be used for height-finding to an accuracy of better than 10 percent (7). A more extensive program to determine the accuracy of the method had to be postponed when the airship was grounded for structural reasons.

Final Experiments

The lobe-counting trials were resumed in September, 1955, in collaboration with Group 45 of the Lincoln Laboratory and the Naval Air Development Unit, and were completed in March, 1956. They were designed to determine the inherent accuracy of the method, the degree to which the lobe structure remains well defined under rough sea conditions, and the effects of atmospheric anomalies on the height-finding accuracy. Numerous flights were made with the radar vehicle at 2800 feet against aircraft targets at 3200, 10,000, 19,800, and 35,000 feet over both smooth and rough seas. During the tests, information on the sea state was provided by both the Texas Tower, located 100 miles east of Cape Cod, and a radar picket ship stationed somewhere east of Nantucket. Table provides a summary of the successful flights made during the height-finding trials. In these experiments, no distinction was made between inbound and outbound runs.

Table 1
Summary of Lobe-Counting Trials

Sea State	Target Altitude	Type of Aircraft	Number of Runs	Airship Altitude
0 to 1	3,200	B-29	9	2800
0 to 1	19,800	B-29	10	2800
0 to 1	35,000	B-47	10	2800
4 to 5	3,200	B-29	6	2800
4 to 5	10,000	P-2V	17	3000
5 to 6	19,800	B-29	16	2800

RESULTS OF TESTS

The individual runs listed in Table 1 were evaluated by counting the number of lobes in each 10-mile interval as determined from the range marks placed on the Sanborn tapes. The family of curves shown in Fig. 2 was used to determine the target altitude from the number of lobes per mile and the median range for each interval. These curves refer to a frequency of 425 Mc and a radar altitude of 3000 feet. Since the airship was flown at an altitude of 2800 feet for all but the 10,000-foot trials, it was necessary to multiply the measured number of lobes per mile by a correction factor of 1.07 (i.e., 3000/2800).

After the individual altitude determinations had been made, the results for all runs at the same nominal target altitude were averaged in each 10-mile interval and the standard deviation σ calculated. Table 2 is a summary of the data obtained from the lobe-counting trials conducted over smooth seas. Nine runs were made against a B-29 at 3200 feet, 10 runs against a B-29 at 19,800 feet, and 10 runs against a B-47 at 35,000 feet. The average altitude is plotted against range in Fig. 8, where the shaded area represents the standard deviation. Table 3 and Fig. 9 give a summary of the data obtained over rough seas from 6 runs made against a B-29 at 3200 feet, 17 runs against a P-2V at 10,000 feet, and 16 runs against a B-29 at 19,800 feet.

A statistical analysis was made of the data summarized in Tables 2 and 3 to determine whether there was any systematic error in the height measurements.* The "Student's t" test (14) was applied to the average altitudes for the various range increments, and it was determined that the experimental data were normally distributed (within 95 percent confidence limits) about the prescribed altitudes. This showed that the measurement technique was free of bias error. The 19,800-foot B-29 trials were an exception, these results being biased toward higher values. No satisfactory explanation has been found.

It appears from Fig. 8 and 9 that the height error, as exemplified by the standard deviation, shows no range dependence. An analysis was conducted to examine this question and no correlation was found between σ and the range. The height error in most other types of height finders is proportional to range, since the elevation angle is the quantity measured directly.

*The author is indebted to Arthur S. Zamanakos, Radar Division, NRL, for this analysis.

Table 2

Summary of Target Altitude Determinations Obtained from the Lobe-Counting Trials. Sea State 0 to 1; Radar Altitude 2800 Feet; Frequency 425 Mc

(a) B-29 3,200 ±100 feet Date: 9/27/55

Range Interval / Run No.	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110
1				3,100	3,000	3,200	3,400	3,600	3,600
2	3,200	3,400	2,800	2,900	3,400	2,900	2,700		3,300
3	3,300	3,200	2,600	3,300	3,600	3,200	2,700	2,600	
4	3,800	3,300	3,100	3,000	3,200	3,600	2,600	2,500	3,000
5					3,300	3,300	3,200	3,300	
6	3,700	3,100	3,000	3,200	3,000	3,200	2,700		
7		3,600	3,400	3,300	2,800	3,200	3,200		
8	3,100	3,300	3,300	3,400	2,800	3,700			
9	3,100	3,000	2,900	3,200	2,800	3,200	3,400		
Average Alt.	3,400	3,300	3,000	3,200	3,100	3,300	3,000	3,000	3,300
Error (feet)	+200	+100	-200	0	-100	+100	200	-200	+100
σ (feet)	300	200	300	200	300	200	300	500	200

(b) B-29 19,800 ±70 feet Dates 9/28/55 and 10/5/55

Range Interval / Run No.	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120-130	130-140	140-150
1		19,400	19,800	18,900	19,300	19,500	20,100	20,200	18,600	22,500	23,800	19,300	20,300
2	22,500	20,000	20,000	18,500	20,200	20,900	21,700	20,200	20,700				
3			19,500	21,000				20,200	20,100	20,800			
4			19,700	19,300	21,700	19,800	19,800	20,200	20,700				
5									20,100	20,800			
6	20,500	21,000	19,600	20,800	20,100	19,000	19,300	19,500	21,300				
7		19,400	21,100	21,100	19,400	21,500	20,800	21,000	23,000	19,500	21,700	18,700	
8	21,100	19,000	19,900	19,700	[illegible]	19,700	19,800	20,200	20,700	20,300	20,800	17,700	
9	20,200	19,400	20,000	20,000	[illegible]	20,900	19,800	20,200	19,200	19,000			
10	20,600	18,600	20,200										
Average Alt.	21,000	19,500	20,000	19,800	20,100	20,200	20,100	20,200	20,500	20,500	22,000	18,800	20,300
Error (feet)	+1,200	-300	+200	0	+300	+400	+300	+400	+700	+700	+2,200	-1,200	+500
σ (feet)	800	700	600	1,000	800	800	800	400	1,200	1,100	1,200	700	

(c) B-47 35,000 feet Dates 10/3/55 and 10/10/55

Range Interval / Run No.	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120
1	39,700	35,000	33,600	34,700	35,000					
2		35,000	33,000	35,500	35,300	33,700	36,200	34,000	34,000	
3		34,800	32,000	36,200	36,300	34,800	31,300	34,000	34,500	35,000
4	40,000	35,000	35,500	34,000	36,300	35,200	34,400	34,400		
5			33,700	37,700	38,300	33,700	34,400	34,400	30,000	
6	39,500	35,000	35,800	36,200	37,300	35,200	32,500	35,500	33,500	35,000
7					37,300	33,700	36,200	30,800		
8				38,800	35,000	35,200	34,400	34,000		
9		34,600	32,000	35,500	34,000	35,200	39,000	34,800		
10		35,000	32,000	34,000	33,000	36,500	36,200			
Average Alt.	39,700	34,900	33,500	35,800	35,800	34,800	35,000	34,000	33,000	35,000
Error (feet)	+4,700	-100	-1,500	+800	+800	-200	0	-1,000	-2,000	0
σ (feet)	200	100	1,400	1,500	1,600	900	2,200	1,300	1,800	

Table 2
Summary of Target Altitude Determinations Obtained from the Lobe-Counting Trials. Sea State 0 to 1; Radar Altitude 2800 Feet; Frequency 425 Mc

(a) B-29 3,200 ±100 feet Date 9/27/55

Range Interval / Run No.	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110
1				3,100	3,000	3,200	3,400	3,600	3,600
2	3,200	3,400	2,800	2,900	3,400	2,900	2,700		3,300
3	3,300	3,200	2,600	3,300	3,600	3,200	2,700	2,600	
4	3,800	3,300	3,100	3,000	3,200	3,600	2,600	2,500	3,000
5					3,300	3,300	3,200	3,300	
6	3,700	3,100	3,000	3,200	3,000	3,200	2,700		
7		3,600	3,400	3,300	2,800	3,300	3,200		
8	3,100	3,300	3,300	3,400	2,800	3,700			
9	3,100	3,000	2,900	3,200	2,800	3,200	3,400		
Average Alt.	3,400	3,300	3,000	3,200	3,100	3,300	3,000	3,000	3,300
Error (feet)	+200	+100	-200	0	-100	+100	200	-200	+100
σ (feet)	300	200	300	200	500	200	300	500	200

(b) B-29 19,800 ±70 feet Dates 9/28/55 and 10/5/55

Range Interval / Run No.	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120-130	130-140	140-150
1		19,400	19,800	18,900	19,300	19,500	20,100	20,200	18,600	22,500	23,600	19,300	20,300
2	22,300	20,000	20,000	18,500	20,200	20,900	21,700	20,200	20,900				
3			19,500	21,000				20,200	20,100	20,800			
4			19,700	19,300	21,700	19,800	19,800	20,200	20,700				
5									20,100	20,800			
6	20,500	21,000	19,600	20,800	20,100	19,000	19,300	19,500	21,300				
7		19,400	21,100	21,100	19,400	21,500	20,800	21,000	23,000	19,500	21,700	18,700	
8	21,100	19,000	19,900	19,600	[illegible]	19,700	19,600	20,200	20,700	20,300	20,800	17,700	
9	20,200	19,400	20,000	20,000	[illegible]	20,900	19,600	20,200	19,200	19,000			
10	20,600	18,600	20,200										
Average Alt.	21,000	19,500	20,000	19,800	20,100	20,200	20,100	20,200	20,500	20,900	22,000	18,600	20,300
Error (feet)	+1,200	-300	+200	0	+300	+400	+300	+400	+700	+700	+2,200	-1,200	+500
σ (feet)	800	700	400	1,000	800	800	800	400	1,200	1,100	1,200	700	

(c) B-47 35,000 feet Dates 10/3/55 and 10/10/55

Range Interval / Run No.	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120
1	39,700	35,000	33,800	34,700	35,000					
2		35,000	33,000	35,500	35,200	33,700	36,200	34,000	34,000	
3		34,800	32,000	36,200	36,300	34,800	31,300	34,000	34,500	35,000
4	40,000	35,000	35,500	34,000	36,300	35,200	34,400	34,400		
5			33,700	37,700	38,300	33,700	34,400	34,400	36,000	
6	39,500	35,000	35,800	36,200	37,300	35,200	32,500	35,500	33,500	35,000
7					37,300	33,700	36,200	30,800		
8				38,800	35,000	35,200	34,400	34,000		
9		34,600	32,000	35,500	34,000	35,200	39,000	34,800		
10		35,000	32,000	34,000	33,000	36,500	36,200			
Average Alt.	39,700	34,900	33,500	35,800	35,800	34,800	35,000	34,000	33,000	35,000
Error (feet)	+4,700	-100	-1,500	+800	+800	-200	0	-1,000	-2,000	0
σ (feet)	200	100	1,400	1,500	1,600	900	2,200	1,300	1,800	

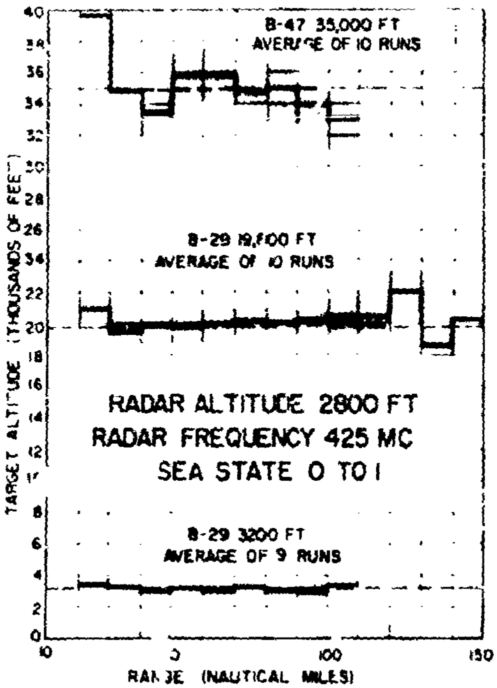

Fig. 8 - Histogram of low sea-state trials

Since no range dependence was found in the height error, it is appropriate to determine a root-mean-square height error over all range intervals. The rms deviation ρ of the measured height from the true height is related to the variance, σ^2 and the error ε of the average of the height readings by the equation*

$$\rho^2 = \sigma^2 + \varepsilon^2. \tag{5}$$

The values for σ and ε used in calculating ρ were obtained from Tables 2 and 3. Table 4 is a summary of the results obtained. It shows that the accuracy of the method, when considered for a large number of trials, is no worse than 10 percent for low-flying aircraft and as good as 4 percent for medium- and high-flying aircraft. Thus limited experience shows that this method affords a means of measuring target altitude quite accurately over either smooth or rough seas and that the lobe structure is not destroyed by a sea state as high as six.

*The author is indebted to Lamont V. Blake, Radar Division, NRL, for pointing out this relationship.

Table 3
Summary of Target Altitude Determinations Obtained from the Lobe-Counting Trials. Sea States 4, 5, and 6; Radar Altitude 2800 Feet; Frequency 425 Mc

(a) B-29 — 3,200 ±100 feet — Date 10 25 55

Run No. \ Range Interval	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110
1		3,000	3,400	3,190	3,300	3,100	2,800	2,800	3,100
2		2,900	2,900	3,300	2,860	3,500	3,100	3,800	3,300
3				3,100	3,400	3,000			
4		3,100	3,100	3,300	2,800	3,600	3,800		
5		3,800	4,000	2,900	3,300	3,200	3,400	3,600	
6			3,390	3,[illegible]	3,500	3,200	3,100	3,000	
Average Alt.		3,200	3,300	3,200	3,200	3,300	3,200	3,390	3,200
Error (feet)		0	+100	0	0	+100	0	+100	0
σ (feet)		400	400	100	300	200	300	400	100

(b) P2V — 10,000 feet — Dates 3 12 56 and 3 15 56

Run No. \ Range Interval	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110
1					9,900	11,200	10,000	9,800	10,400
2	9,700	9,100	9,700	9,800	9,700	11,000	9,800		
3			9,900	9,700	10,200				
4	9,300	9,900							
5	10,000	9,900		10,900					
6	10,200	10,000	9,500	10,200	10,300	9,700			
7	10,000	9,800	9,300	9,000	10,100				
8	10,000	10,100	10,200	9,200	10,200				
9	11,000	9,800	10,300	10,800	19,900	10,900			
10	10,200	10,100	9,900	10,100	10,600	10,400			
11	10,100	10,000	10,900	10,300	10,600	10,400			
12		9,600	10,300	9,800	10,400	9,800			
13	10,500	10,100	11,100	10,100	9,500				
14	10,000	10,100	10,100	9,500	10,300	10,400			
15	10,600	9,900	10,[illegible]00	10,400					
16		8,800	10,200	10,000	9,700	10,000			
17	10,600	9,800	10,300	9,400	9,800				
Average Alt.	10,200	9,800	10,200	9,900	10,100	10,400	9,900	9,800	10,400
Error (feet)	+200	200	+200	-100	+100	+400	-100	-200	+400
σ (feet)	400	400	400	500	300	500	100		

(c) B-29 — 19,800 ±70 feet — Dates 10 25 55 and 3 15 56

Run No. \ Range Interval	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120-130
1		19,800	19,800	20,700	19,400	19,400	19,800				
2	19,900	20,800	20,600	20,000	20,400	19,400	21,200	19,600			
3		18,900	19,900	20,300	20,100	19,800	19,000	19,600	21,300		
4		20,600	19,800	19,800	19,200	19,000	19,400				
5			20,600	19,900	21,000	18,800	19,800	18,200			
6	20,800	20,600	20,000	19,600	20,800	20,300	20,500				
7		20,300	19,700	21,200	21,800	20,000					
8	20,900	19,500	20,500	20,700		19,400					
9					18,400	19,500	17,600	19,000			
10				21,600	18,900	22,200					
11					19,400	21,100	19,600	19,000	21,[illegible]	20,300	20,800
12		21,000	20,100	20,400	20,800	21,000	20,600	22,000	18,300	19,000	
13			19,700	20,500	21,900	18,900	17,800	20,200	18,300		
14		20,000	18,300	17,500	18,900	18,900		25,200	18,300	21,800	
15		18,800	19,200	17,200	22,500	20,200	19,600	22,000	20,700	20,300	
16		19,400	19,700		20,000	21,000	19,600	19,000	20,700		
Average Alt.	20,500	20,000	19,800	20,000	20,200	19,900	19,700	19,900	19,900	20,400	20,[illegible]00
Error (feet)	+700	+200	0	+200	+400	+100	-100	+100	+100	+600	+1,000
σ (feet)	400	700	600	1,200	1,200	900	800	1,200	1,400	1,000	

*Radar altitude for these runs was 3,000 feet †Sea state for these runs was 5 to 6

EFFECT OF HIGH SEA STATES

From its inception, the major concern with regard to the lobe-counting method was that it would become inaccurate or fail completely under high sea-state conditions since it depends on strong specular reflection producing a well-defined lobe structure. When the surface is rough compared with a wavelength, it is reasonable to expect that perfect

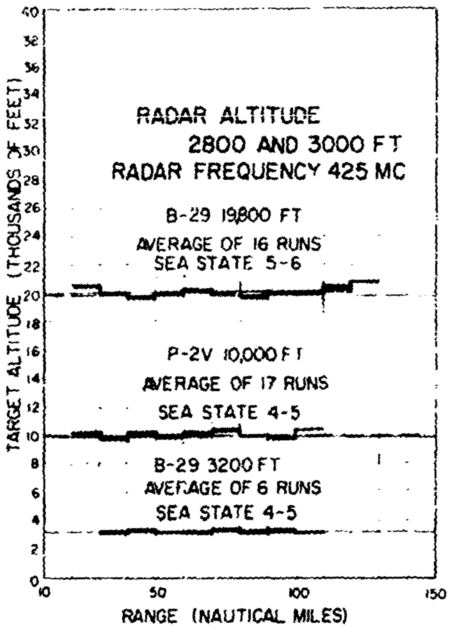

Fig. 9 - Histogram of high sea-state trials

reflection will no longer be obtained, particularly for rays having large angles of incidence. This would result in a gradual decrease in the maximum-to-minimum ratio in the lobe structure, particularly at short ranges. Since no positive data were available with regard to the reflection coefficient at uhf for rough seas, the flights at altitudes of 3200, 10,000, and 19,800 feet against sea states as high as six were of particular interest. This series of flights showed no appreciable deterioration of the lobe structure. Figures 10 through 13 show the lobe structure as it was recorded on Sanborn tape. Two separate flights of a B-29 at 19,800 feet, one over smooth and one over rough seas, are shown in these figures, matched according to range intervals, from 30 to 100 nautical miles. The lobe structure under all conditions is clearly defined. A comparison of the respective signal deflection amplitudes is not in order since the runs were made with the equipment under different adjustments and by different personnel. As was determined later, the run over a very rough sea was range limited because of an antenna feed structure failure. The high sea-state run does have more hash on the recorded signal, especially in the 90- to 100-mile interval. Figure 10 contains the critical short-range section of the runs. It will be noted that for the high sea-state record, the maximum-to-minimum ratio is very high in the region from 34 to 37 nautical miles. At this point a second aircraft entered the range gate of the tracker causing a steady return for the next 3 miles, after which a very finely divided lobe structure resulted. Strong sea return below 30 miles caused the data to become too obscure to be usable. Thus, the lobe structure at the high sea states remained well defined, the Sanborn tape records of the return signal were quite readable down to the range at which sea clutter was observed, and the accuracy of the method in determining target altitude is maintained in the region where the signal is not obscured by clutter.

Table 4
Root-Mean-Square Deviation
of Measured Height from the True Height

Sea State	Target	Designated Target Altitude (feet)	ρ (feet)	ρ (percent)
0 to 1	B-29	3,200	280	8.8
0 to 1	B-29	19,800	926	4.7
0 to 1	B-47	35,000	1420	4.1
4 to 5	B-29	3,200	301	9.4
4 to 5	P-2V	10,000	419	4.2
5 to 6	B-29	19,800	1012	5.1

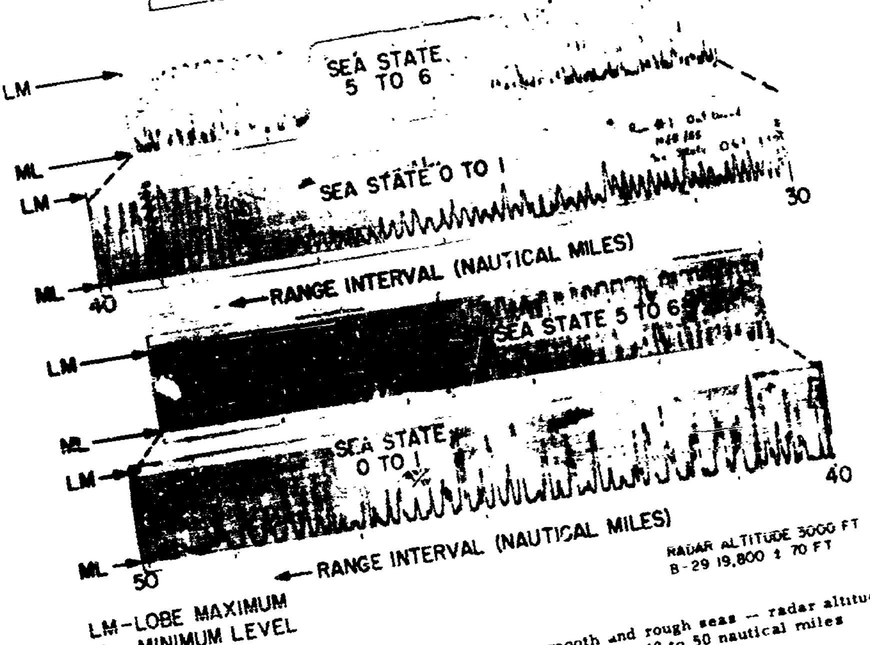

Fig. 10 - Tape record of typical flights over both smooth and rough seas — radar altitude 2800 feet; target altitude 19,800 feet; range 30 to 40 and 40 to 50 nautical miles

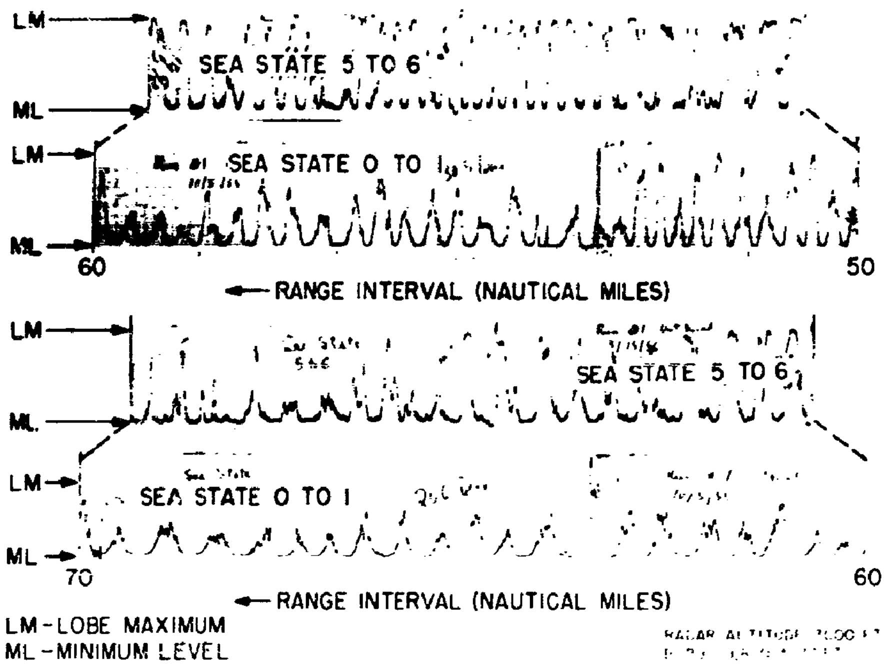

Fig. 11 - Tape record of typical flights over both smooth and rough seas -- radar altitude 2800 feet; target altitude 19,800 feet; range 50 to 60 and 60 to 70 nautical miles

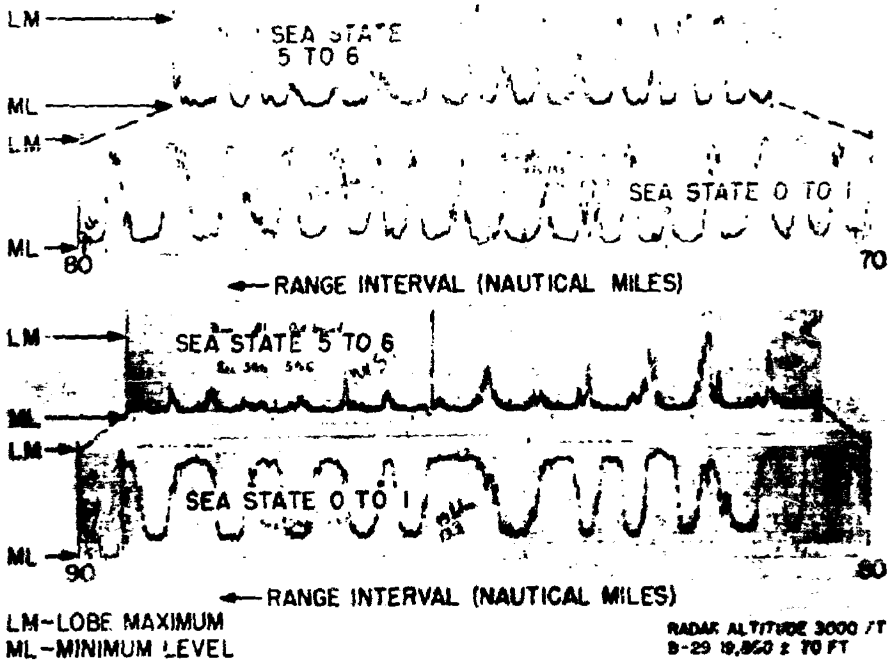

Fig. 12 - Tape record of typical flights over both smooth and rough seas -- radar altitude 2800 feet; target altitude 19,800 feet; range 70 to 80 and 80 to 90 nautical miles

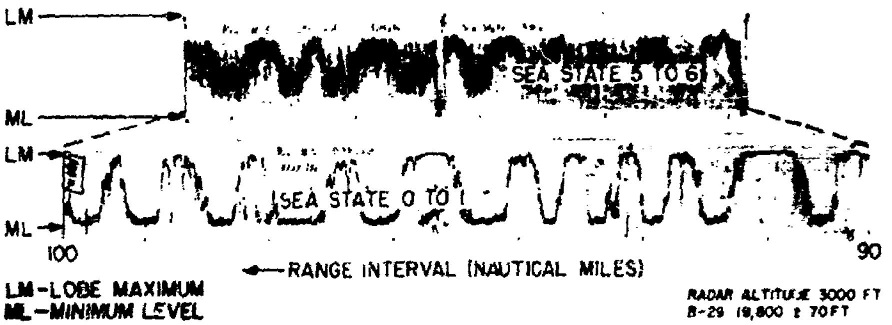

Fig. 13 - Tape record of typical flights over both smooth and rough seas -- radar altitude 2800 feet; target altitude 19,800 feet; range 90 to 100 nautical miles

ATMOSPHERIC ANOMALIES

It was hoped that refractometer soundings of the layered atmosphere could be made before, during, and after each airship operation in order that the resulting refractive index profiles could be correlated with the height-finding data obtained. This was not possible because the NADEVU refractometer was inoperative during the months when the extensive trials were conducted. Since no adverse effects were noticed while the trials were being conducted under a variety of atmospheric conditions, it is felt that anomalies, where present, would not have enough of an effect on the height-finding to defeat the method.

BARRIER EXERCISES

On May 26, 1955, the Naval Air Development Unit conducted a 24-hour barrier operation with two ZPG-2 airships flying one mile apart, back and forth in a straight line 50 miles long orientated north and south 60 miles east of Boston, Massachusetts (15). One airship carried the low-power uhf radar and the other an AN/APS-20E radar. The objectives of the exercise were (a) to detect, track, and record all aircraft penetrating the barrier, (b) to compare the detection capabilities of the two radars employed, and (c) to evaluate further the lobe-counting method of height-finding. NRL personnel participated in the exercise by providing height information on specific targets as requested.

The enemy force was considered to be all aircraft, both civil and military, inbound from Europe to Boston and New York via specified control lanes and all itinerant aircraft operating in the U.S. northeast coastal area. Twenty-seven targets were detected with the uhf radar at ranges varying from 40 to 158 nautical miles. Height determinations were made on 17 unknown targets at ranges from 40 to 140 nautical miles by searchlighting the target for approximately two minutes. Indicated altitudes varied from 17,000 feet to less than 1000 feet, with one unknown target at 50,000 feet. A clear indication was obtained on all measurements and a comparison of altitudes was obtained for 9 of the 12 targets reported by the GCI stations located at North Truro, Massachusetts, and Portland, Maine. There was no satisfactory overall agreement between the results obtained with the uhf and the height-finding radars located at the GCI stations. The capability of the uhf radar in performing the dual function of a search and height-finding radar was encouraging.

A second unscheduled barrier exercise was conducted on October 20, 1955. As originally planned, the flight was a scheduled operation for the ZPG-2 airship to run tests against a P-2V. When the target plane was forced to cancel because of engine failure, the GCI station located at North Truro, Massachusetts, was contacted and asked to furnish information with regard to air traffic enroute to and from Europe. The aim was to obtain a comparison of altitude determinations made by the GCI station and the uhf radar. Only targets held by both systems were considered. The results of this exercise are presented in Table 5. Unfortunately the GCI station height-finder radar was inoperative during most of the exercise. With one exception, the altitude determinations made with the uhf radar were in close agreement with the altitudes listed in the target aircraft flight plans. Though somewhat limited in scope, the operation was considered a success, and demonstrated that the lobe-counting method provides a means of determining target altitudes at long ranges if the uhf search system can be spared for a minute or two.

Table 5
Results of Barrier Exercise

Unknown Target	Greenwich Mean Time	Bearing (degrees)	Detection Range (naut mi)	UHF Altitude Determination	GCI Altitude Determination	Flight Plan Report	Remarks
1	1955	060	59	8,300	-	7,000	
2	2025	100	70	-	-	-	
3	0230	090	46	19,000	-	19,000	Tracked to 194 naut Mi
4	0455	054	123	10,500	-	10,000	C-124 Aircraft
5	0545	095	185	-	-	-	
6	0723	057	125	17,700	10,000	18,000	
7	0751	075	111	12,000	-	12,000	
8	0828	072	109	-	-	-	
9	0848	071	155	8,300	-	8,000	
10	1005	060	82	4,300	-	8,000	C-124 Aircraft
11	1030	055	92	6,000	-	-	No. GCI Report

OPERATIONAL FEASIBILITY OF THE METHOD

For operational use, the loss of the radar search function should be minimized. A rough indication of height can be obtained by counting just one lobe; however, to obtain reasonably accurate height measurement, two lobes are necessary and three are preferred since this would insure two good maxima and minima. With this criterion in mind, the curves shown in Fig. 14 were plotted to show the time required for (a) a 300-knot target and (b) a 600-knot target. These are for target altitudes of 3200, 5000, 10,000, 20,000, and 40,000 feet and refer to a frequency of 425 Mc and a radar altitude of 3000 feet. The curves for the target with a radial velocity of 300 knots also apply to the time required for a 200-knot target to traverse two lobes and a 100-knot target one lobe. The 600-knot target curves can be used to determine the time required for a 400-knot target to traverse two lobes and a 200-knot target one lobe.

If a time limitation is imposed on any altitude determination, the maximum range at which height-finding can be accomplished (assuming, for example, that three lobes must be traversed) is thus limited. The maximum height-finding range will be limited to various percentages of the horizon range depending on the target altitude and the time allotted the height-finding function as shown by Table 6 which refers to a 600-knot aircraft, a radar altitude of 3000 feet, and a frequency of 425 Mc (Fig. 14(b)).

The greatest limitation is thus seen to occur for low-altitude targets. If 3 minutes are available for height-finding, the limitation is not too severe for the lowest target shown (3200 feet). Even with a one-minute time limit, a very worthwhile height-finding capability is provided, especially on high-altitude targets.

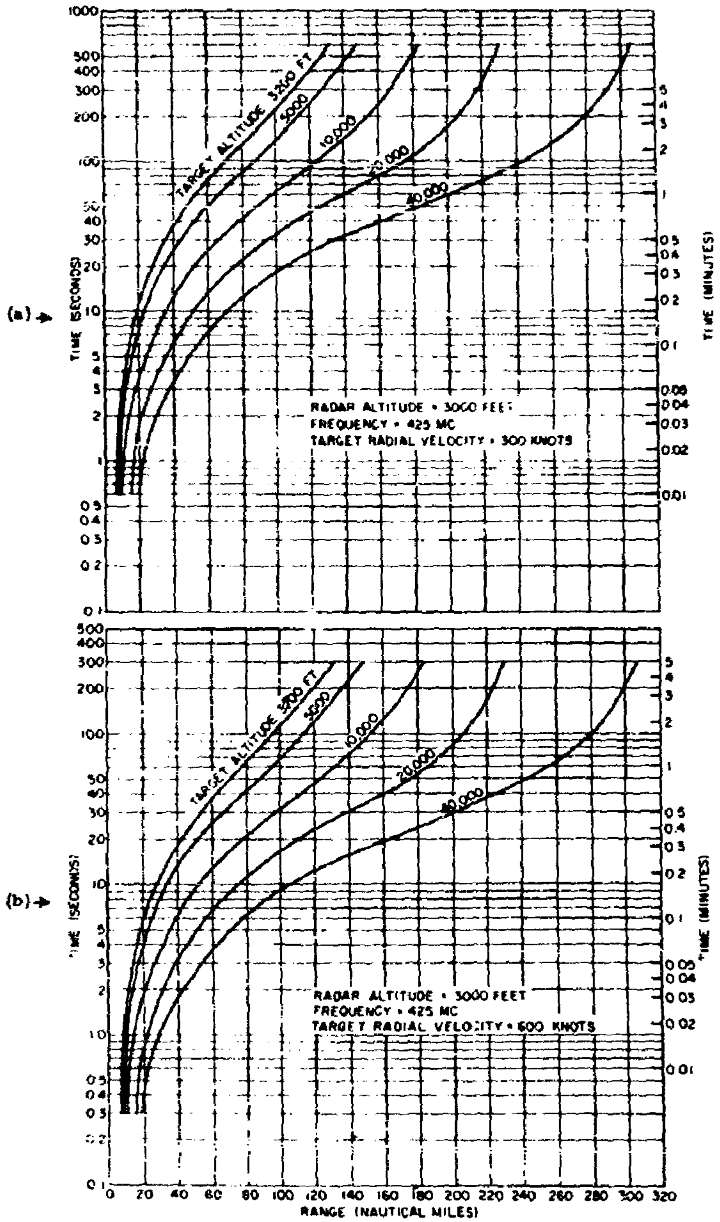

Fig. 14 - Time required for aircraft target to traverse three lobes: (a) 300-knot target and (b) 600-knot target

Table 6
Maximum Height-Finding Range and Its Percentage of the Horizon Range for Indicated Time Allotted to Height Determination

Target Altitude (feet)	Horizon Range (miles)	1 Minute		2 Minutes		3 Minutes	
		Max H-F Range	Percent	Max H-F Range	Percent	Max H-F Range	Percent
3,200	137	78	57	103	75	117	85
5,000	154	[illegible]5	62	120	78	134	87
10,000	190	132	69	160	84	172	91
20,000	241	186	77	212	88	222	92
40,000	313	256	82	287	92	298	95

Radar altitude 3000 ft; frequency 425 Mc; target radial velocity 600 knots

CONCLUSIONS

1. The lobe-counting method of height-finding is feasible for use against isolated, constant-altitude targets.

2. The height determination on each target requires diverting the radar from its normal search function for as long as 1 to 2 minutes.

3. This method can be used in the presence of sea states as high as 6 from near the initial detection range in to the range where the echo is obscured by sea clutter.

4. The method is accurate to about 9 percent for low-flying targets and 4 to 5 percent for medium- and high-flying targets.

ACKNOWLEDGMENTS

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UNITED STATES GOVERNMENT

memorandum

5300-31

DATE: 29 June 1998

REPLY TO ATTN OF: Code 5300

SUBJECT: REQUEST TO DECLASSIFY NRL REPORTS

TO: Code 1221.1 (C. Rogers)

1. It is requested that the NRL Reports listed below be declassified. The information contained in these reports has become public knowledge in the many years since first classified.

Declassified, public release.

3706 AD-C954460	4371 AD-038472	[redacted]	[redacted]	5338 AD-312117	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	5399 AD-314113	5540 AD-320263
[redacted]	[redacted]	5126 AD/62728	5247 AD-304847	5403 AD-312699	5570 AD-320955
[redacted]	[redacted]	[redacted]	[redacted]	5441 AD-315354	
4284 AD031076	4878 AD-125352	5197 AD302457	[redacted]	5536 AD-343165	

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Radar Division

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